

FIRST LHC CONSTRAINTS ON ANOMALOUSLY INTERACTING NEW VECTOR BOSONS

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Abstract. It was recently proposed to extend the Standard Model by means of new spin-1 chiral Z^* and $W^{*\pm}$ bosons with the internal quantum numbers of the electroweak Higgs doublets. These bosons have unique signatures in transverse momentum, angular and pseudorapidity distributions of the final leptons, which allow one to distinguish them from other heavy resonances. With 40 pb^{-1} of the LHC proton-proton data at the energy 7 TeV, the ATLAS detector was used to search for narrow resonances in the invariant mass spectrum of e^+e^- and $\mu^+\mu^-$ final states and high-mass charged states decaying to a charged lepton and a neutrino. From the search exclusion mass limits of $1.15 \text{ TeV}/c^2$ and $1.35 \text{ TeV}/c^2$ were obtained for the chiral neutral Z^* and charged W^* bosons, respectively. These are the first direct limits on the W^* and Z^* boson production.

1 Chiral boson model

New heavy neutral gauge bosons are predicted in many extensions of Standard Model (SM). They are associated with additional $U(1)'$ gauge symmetries and are generically called Z' bosons. The minimal gauge interactions of these bosons with matter lead to the well-known angular distribution of outgoing leptons (the Z' decay product) in the dilepton center-of-mass reference frame. In addition, another type of spin-1 bosons may exist, which leads to a different signature in the angular distribution. This follows from the presence of different types of relativistic spin-1 fermion currents $\bar{\psi}\gamma^\mu(1\pm\gamma^5)\psi$ and $\partial_\nu[\bar{\psi}\sigma^{\mu\nu}(1\pm\gamma^5)\psi]$, which can couple to the corresponding bosons. The mesons assigned to the tensor quark states are some types of “excited” states as far as the only orbital angular momentum with $L = 1$ contributes to the total angular momentum, while the total spin of the system is zero. This property manifests itself in their derivative couplings to matter and a different chiral structure of the anomalous interactions in comparison with the minimal gauge ones.

Let us assume that the electroweak gauge sector of the SM is extended by a doublet of new spin-1 *chiral* bosons \mathbf{W}_μ^* with the internal quantum numbers of the SM Higgs boson. There are at least three different classes of theories, all motivated by the Hierarchy problem, which predict new vector weak doublets with masses not far from the electro-weak scale [1]. It is possible to point out several model-independent and unique signatures which allow one to identify production of such bosons at the hadron colliders [2].

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Since the tensor current mixes the left-handed and right-handed fermions, which in the SM are assigned to different representations, the gauge doublet should have only anomalous interactions

$$\mathcal{L}^* = \frac{g}{M} \left(\partial_\mu W_\nu^{*-} \partial_\mu \bar{W}_\nu^{*0} \right) \bar{D}_R \sigma^{\mu\nu} \begin{pmatrix} U_L \\ D_L \end{pmatrix} + \frac{g}{M} (\bar{U}_L \bar{D}_L) \sigma^{\mu\nu} D_R \begin{pmatrix} \partial_\mu W_\nu^{*+} \\ \partial_\mu W_\nu^{*0} \end{pmatrix}, \quad (1)$$

where M is the boson mass, g is the coupling constant of the $SU(2)_W$ weak gauge group, and U and D generically denote up-type and down-type leptons and quarks. These bosons, coupled to the tensor quark currents, can be considered as *excited* states. For comparison we will consider topologically analogous gauge interactions of the Z' boson

$$\mathcal{L}'_{NC} = \frac{g}{2} (\bar{\ell} \gamma^\mu \ell + \bar{d} \gamma^\mu d) Z'_\mu \quad (2)$$

with the same mass M . The coupling constants are chosen in such a way that all fermionic decay widths in the Born approximation of the both neutral bosons are identical. It means that their total production cross sections at the hadron colliders are nearly equal up to next-to-leading order corrections. Their total fermionic decay width $\Gamma = \frac{g^2}{4\pi} M \approx 0.034M$ is sufficiently narrow and they can be identified as resonances in the Drell–Yan process.

Up to now, any excess in the yield of the Drell–Yan process with high-energy invariant mass of the lepton pairs remains the clearest indication of possible production of a new heavy neutral boson at the hadron colliders. The peaks in the dilepton invariant mass distributions originate from the Breit–Wigner propagator form, which is *the same* for both the gauge and chiral *neutral* bosons in the Born approximation. Concerning discovery of the *charged* heavy boson at the hadron colliders one believes that the cleanest method is detection of its subsequent leptonic decay into an isolated high transverse-momentum charged lepton. In this case the heavy new boson can be observed through the Jacobian peak in the transverse p_T (or m_T) distribution. It has become proverbial that the Jacobian peak is an inevitable characteristic of any two-body decay. However, it is not the case for decays of the new chiral bosons [3]. It has been found in [4] that tensor interactions lead to a new angular distribution of the outgoing fermions

$$\frac{d\sigma(q\bar{q} \rightarrow Z^*/W^* \rightarrow f\bar{f})}{d\cos\theta} \propto \cos^2\theta, \quad (3)$$

in comparison with the well-known vector interaction result

$$\frac{d\sigma(q\bar{q} \rightarrow Z'/W' \rightarrow f\bar{f})}{d\cos\theta} \propto 1 + \cos^2\theta. \quad (4)$$

The absence of the constant term in the first case results in very new experimental signatures [3]. The angular distribution for vector interactions (4)

includes a nonzero constant term, which leads to the kinematical singularity in the p_T distribution of the final fermion. This singularity is transformed into a well-known Jacobian peak due to a finite width of the resonance. In contrast, the pole in the decay distribution (3) of the Z^*/W^* bosons is canceled out and the fermion transverse momentum p_T distribution even reaches zero at the kinematical endpoint $p_T = M/2$. A crucial difference between the neutral chiral bosons and other resonances should come from the analysis of the angular distribution of the final-state leptons with respect to the boost direction of the heavy boson in the rest frame of the latter (the Collins-Soper frame [5]). Instead of a smoother angular distribution for the gauge interactions a peculiar “swallowtail” shape of the chiral boson distribution occurs with a dip at $\cos\theta_{CS}^* = 0$. Neither scalars nor other particles possess such a type of angular behavior (see also [6]).

2 The first experimental constraints on the chiral bosons

The first direct experimental search for the excited chiral vector bosons was performed by the ATLAS collaboration [7,8] in 2010. At the LHC energy of 7 TeV with the integral luminosity around 40 pb^{-1} the ATLAS detector was used for searching for narrow resonances in the invariant mass spectrum above $110 \text{ GeV}/c^2$ of e^+e^- and $\mu^+\mu^-$ final states [9]. The main physical results relevant to our discussion are presented in Fig. 1. It is seen that both the

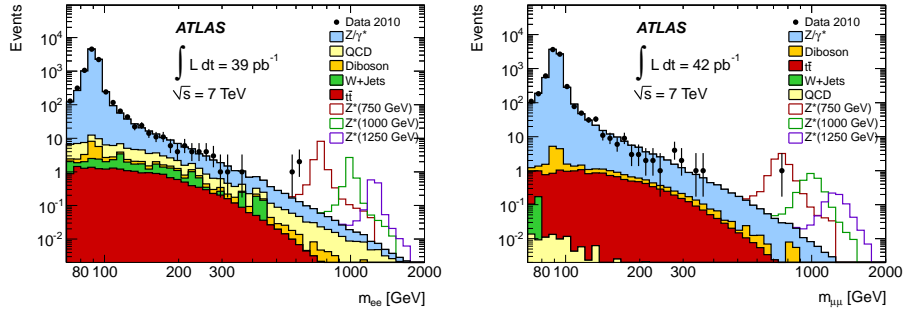


Figure 1: Dielectron (left) and dimuon (right) invariant mass distribution, compared to the stacked sum of all expected backgrounds and with three example Z^* signals overlaid.

dielectron and dimuon invariant mass distributions are well described by the prediction from SM processes. Nevertheless, these distributions were for the first time used to obtain a lower direct mass limit of $1.152 \text{ TeV}/c^2$ for the neutral chiral Z^* boson. This is the first direct mass limit on this particle. The Z^* limits are about $100\text{--}200 \text{ GeV}/c^2$ more stringent than the corresponding limits on all considered Z' bosons.

Furthermore, the ATLAS collaboration searched for high-mass states, such as heavy charged gauge bosons, decaying to a charged lepton and a neutrino [10]. The search for heavy charged resonances inclusively produced at the LHC looks more complicated than the search for neutral states due to the absence of the second decay particle — the undetectable neutrino. In this case the kinematic variable used to identify the W'/W^* is the transverse mass $m_T = \sqrt{2p_T E_T^{\text{miss}}(1 - \cos \phi_{l\nu})}$. Here p_T is the lepton transverse momentum, E_T^{miss} is the magnitude of the missing transverse momentum, and $\phi_{l\nu}$ is the angle between the p_T and missing E_T vectors. The main physical results relevant to our consideration are given in Fig. 2. The agreement between the data and

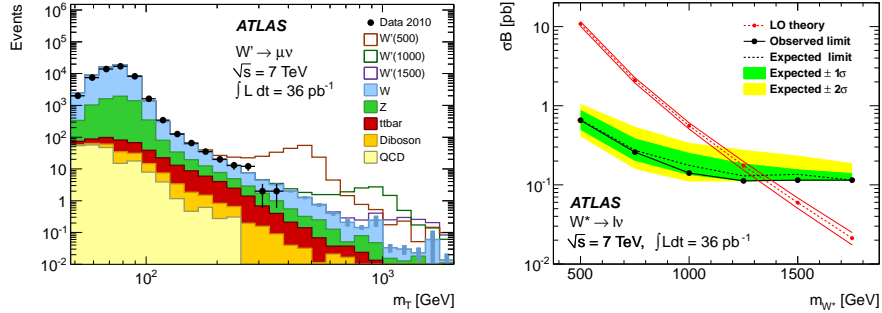


Figure 2: Spectra of m_T for the muon decay channel (left panel). Limits at 95% C.L. for W^* production in the combination of both lepton decay channels (right panel). The solid lines show the observed limits with all uncertainties. From [10].

the expected background is rather good. The lower mass limits expected and obtained from these measurements are depicted in the right panel of Fig. 2. The intersection between the central theoretical prediction and the observed limits provides the 95% C.L. lower limit on the mass. It was found that the charged chiral W^* boson was excluded for masses below $1.350 \text{ TeV}/c^2$. These are the first direct limits on the W^* boson production.

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